Toward a Universal Sea Spray Source Function (UNISOURCE)

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LONG TERM GOALS

The long-term goals of the research are to understand and assess the effects of the atmosphere on the detection of targets at low altitudes over sea in coastal regions using IR and radar systems. Effects considered are transmission losses due to aerosols and water vapor, effects of turbulent fluctuations of the air temperature on blurring and scintillation, and effects of vertical temperature and water vapor gradients on IR and rf refractivity.

OBJECTIVES

The objectives of the research performed in the framework of the present grant are to further analyze data from the EOPACE and RED experiments, with new efforts focussing on the sea spray source function, i.e.:

– to determine the turbulence and refractivity in the inhomogeneous coastal boundary layer and their effects on imaging of low altitude point targets;

– to determine effects of scintillation and refraction in the MW IR band as function of environmental conditions through measurements with a camera mounted ashore at a range of levels above the sea surface, looking at a source mounted on FLIP;

– to improve the description of the aerosol size distribution as function of height and meteorological parameters;

– to determine the effect of sea spray aerosol on IR propagation as function of environmental conditions;

– to determine the generation of sea spray aerosol from breaking wind waves by the bubble-mediated mechanism and by direct tearing from the wave tops, the dispersal of freshly produced aerosol in the surface layer and the influence of wave induced turbulent phenomena, and the subsequent transport of the aerosol throughout the atmospheric boundary layer.

APPROACH

Data from the EOPACE IOP's at the California coast and in Duck, North Carolina in 1996-1999 and from the RED experiments at the coast of Hawaii in August/September, 2001, are further analyzed and interpreted. Research in FY03 was focused on the analysis of aerosol and bubble data from the RED experiments, and on refraction effects on near-surface IR propagation using results from EOPACE and other experiments. Contributions to EOPACE and RED experiments were described in previous annual

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reports. Preparations are made to determine a formulation for the production of primary marine aerosol that applies in a wide variety of conditions. As part of this, a sea spray aerosol workshop is organized in the UK in the spring of 2004.

WORK COMPLETED

Work completed in years prior to FY03 was summarized in earlier reports. In FY03 the following work was completed:

- The publication of the results from the analysis of IOP4 has appeared in Applied Optics [Doss-Hammel et al., 2002]. A publication with results from other IOP's, focussing on refraction effects, has been submitted for publication [De Jong et al., 2003]. Results from laboratory experiments on primary marine aerosol production by bubble bursting have been published in J. Geophys Res. [Mårtensson et al., 2003]. An analysis of data from a Mediterranean site (Porquerolles, France) has been published in Opt. Eng. [Piazzola et al., 2003]. See the publications section for articles published and submitted in FY03 on related subjects.
- TNO-FEL contributed to a RED overview paper that has been submitted for publication in BAMS [Anderson et al., 2003].
- The data from the Rough Evaporation Duct (RED) experiments off Oahu (HI) in August/September 2001 have been partly analyzed. Initial results were presented at several scientific conferences (see listing in 'Publications').
- An overview of primary marine source functions is in press [Schulz et al., 2003].

RESULTS

During the Rough Evaporation Duct (RED) experiments off Oahu (HI) in August/September 2001, aerosol particle size distributions were measured with optical particle counters and a volatility system. The volatility system was also utilised in a combination with a sonic anemometer and a CPC to measure primary marine aerosol production by application of the eddy covariance technique. Particle size distribution profiles were measured with Rotorod impaction samplers [De Leeuw, 1986]. Bubble size distributions were measured with an optical bubble measuring system [De Leeuw and Cohen, 2001]. Lidar measurements were made to characterise the boundary layer structure (cf. Kunz et al. [2002] for a description of the lidar system and the type of measurements). All these measurements were made from FLIP. IR propagation measurements were made between FLIP and a number of sites ashore [De Jong, 2002].
The aerosol size distributions and volatility spectra have been analysed and used in the Coastal Aerosol Transport model CAT [Vignati et al., 2001] to derive the sea salt source function. The volatility spectra recorded at a temperature of 600^{o}C after subtraction of those recorded at the higher temperature, were used to ascertain that only sea spray was measured. The size spectra were binned in 1 ms^{-1} wind speed intervals. Particles larger than 1 μm in diameter, the concentrations of which were falling off due to inefficient collection by the volatility system, were deleted. Likewise, the concentrations of particles smaller than 2 μm measured with the optical particle counter were high due to the occurrence of other constituents than sea salt. Although it cannot be ruled out that larger particles did not contain other constituents than sea salt, these particles were retained to construct sea salt size spectra in the size range from 0.2 to >40 μm for wind speeds from 5 to 10 ms^{-1}. The results are shown in Figure 1. It is noted that the relative humidity (RH) during the RED experiments were always close to 80%, and hence no humidity corrections were needed.

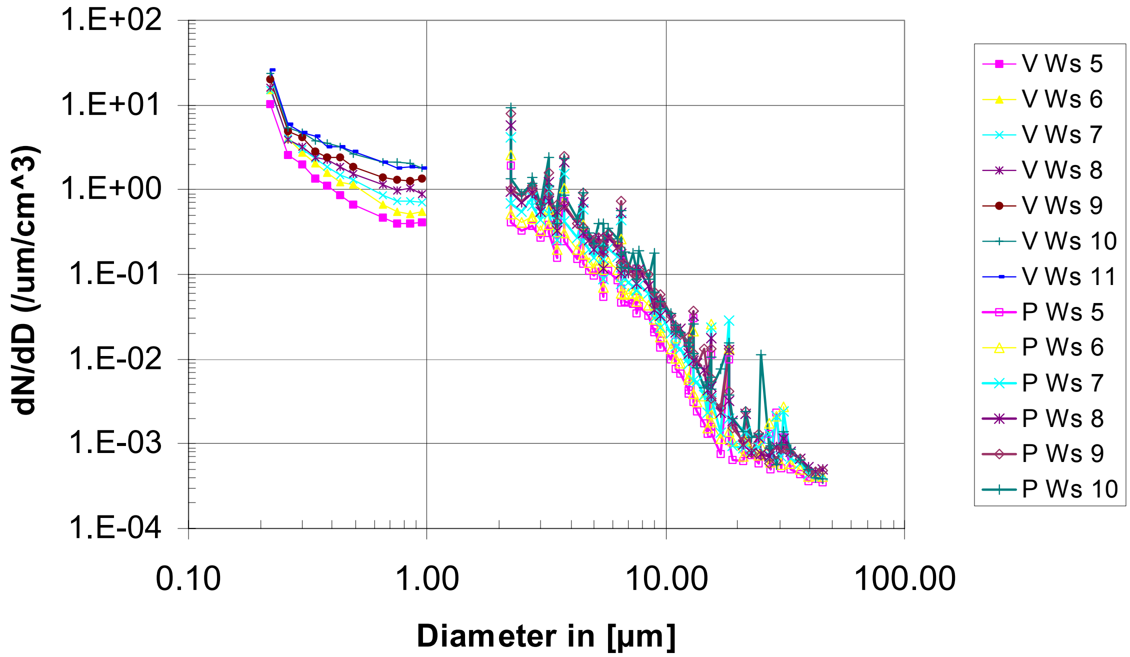


Figure 1. Wind speed binned size spectra derived from the volatility measurements (denoted by VWs nn, see legend) and the optical particle counters (denoted by PWs nn).

These size spectra were subsequently used to construct bimodal lognormal size distributions in the radius range 0.1-10 µm:

$$y = A\exp\left[C\ln\left(\frac{R_{80}}{B}\right)^2\right] + D\exp\left[F\ln\left(\frac{R_{80}}{E}\right)^2\right]$$

where R_{80} is the particle radius in micron at 80 % relative humidity and *A, B, C, D, E, F* are given in the following table for wind speed from 5 to 10 m/s.

Table 1. Coefficients from fitting Lognormal size distributions to the combined volatility and optical particle counter data, binned in 1 ms^{-1} wind speed intervals between 5 and 10 ms^{-1}.

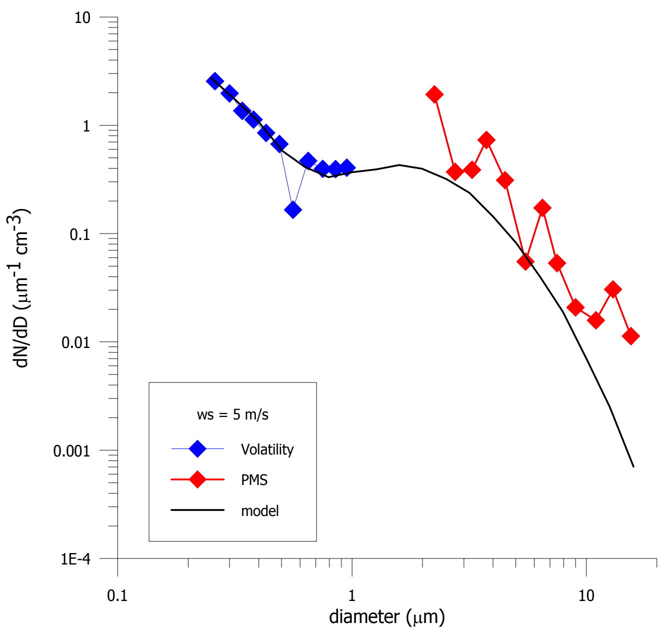
WS	**5**	**6**	**7**	**8**	**9**	**10**
A	8	8.5	12.496	11.497	14.494	14.494
B	0.0643	0.0643	0.0643	0.0643	0.0643	0.0643
C	1.126	1.126	1.027	0.829	0.829	0.631
D	1	1	1.8	2.2	2.7	3.5
E	0.7996	0.7996	0.7996	0.7996	0.7996	0.7996
F	1.099	1.099	1.099	1.099	1.099	1.099

These values were used to derive the wind speed dependence of the parameters *A, C* and *D*:

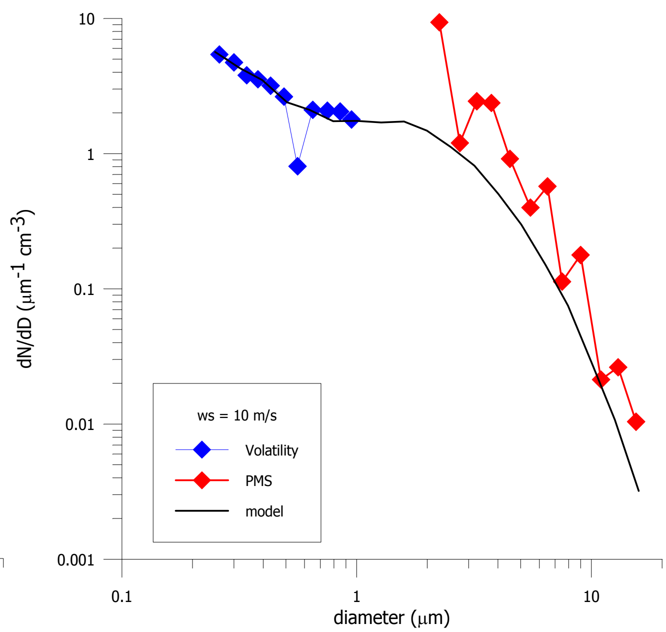
$$A(ws) = 1.4129ws + 0.9831 \qquad R^2(A) = 0.87$$
$$C(ws) = -0.1018ws + 1.6917 \qquad R^2(C) = 0.93$$
$$D(ws) = 0.5143ws - 1.8238 \qquad R^2(D) = 0.96$$

where R^2 are the correlation coefficients:

The CAT model has been run using wind speed from 5 to 10 m/s. The column has been advected for 300 km over the open sea in neutral conditions. The Boundary Layer height has been set to 1000 m and the concentrations at 16 m height are reported. The initial size distribution was set to zero for both sea salt and continental aerosols. Sea salt is supposed to be generated by the sea surface. At the end of the trajectory the aerosol concentrations predicted by CAT have been compared to the concentrations measured by PMS and the volatility system, see Figure 2 for results for 5 and 10 ms^{-1}. The submicron particles were given most weight because they are only sea salt. For the larger particles they are high by roughly a factor of 2. This supports the earlier suggestion that these larger particles do not exclusively consist of sea spray, likely due to the occurrence of organics, or due to residues from other origin, long range transported and transformed due to a variety of processes.



5 ms-1



10 ms-1

Figure 2. Comparison of CAT-calculate sea spray size distributions with sea spray size distributions derived from the volatility measurements (blue) and the optical particle counters (red).

Thus exercise resulted in the following expression for the sea salt source function:

$$\frac{dF_N}{dr} = c\left(\sum_{i=1}^{2} A_i e^{-C_i * \ln\left(\frac{r}{r_i}\right)^2}\right), \qquad \text{in } \mu m^{-1}\, m^{-2} s^{-1}$$

where:
$A_1 = 1.41u + 0.98$
$A_2 = 0.51u - 1.82$
$C_1 = -0.1u + 1.69$
$C_2 = 1.09$
$R_1 = 0.0643$
$R_2 = 0.7996$
$c = (0.24u + 0.4)*10^4$

In Figure 3, this source function is compared with the ones derived by Monahan et al. [1986] and Smith et al. [1993], that are commonly referred to in the literature, and the recently published source function by Vignati et al. [2001]. For the smaller particles the source functions are quite close, although at the lower end the Vignati et al. source function decreases toward smaller sizes, in good agreement with recent measurements. For particles with radius around 1 µm, the current source function is higher than all other ones, while the curvature suggests that for larger particles it may approach Vignati et al. The higher concentrations in the 1 µm range may be a water temperature effect: during RED it was about 28°C, whereas the other source functions are based on data collected in colder water of the North Atlantic. However, the preliminary analysis of direct covariance measurements of the primary marine aerosol flux, including data from RED and spanning a water temperature range from 0°C to 28°C, does not show a clear dependence. This analysis is continued, and new laboratory experiments are planned.

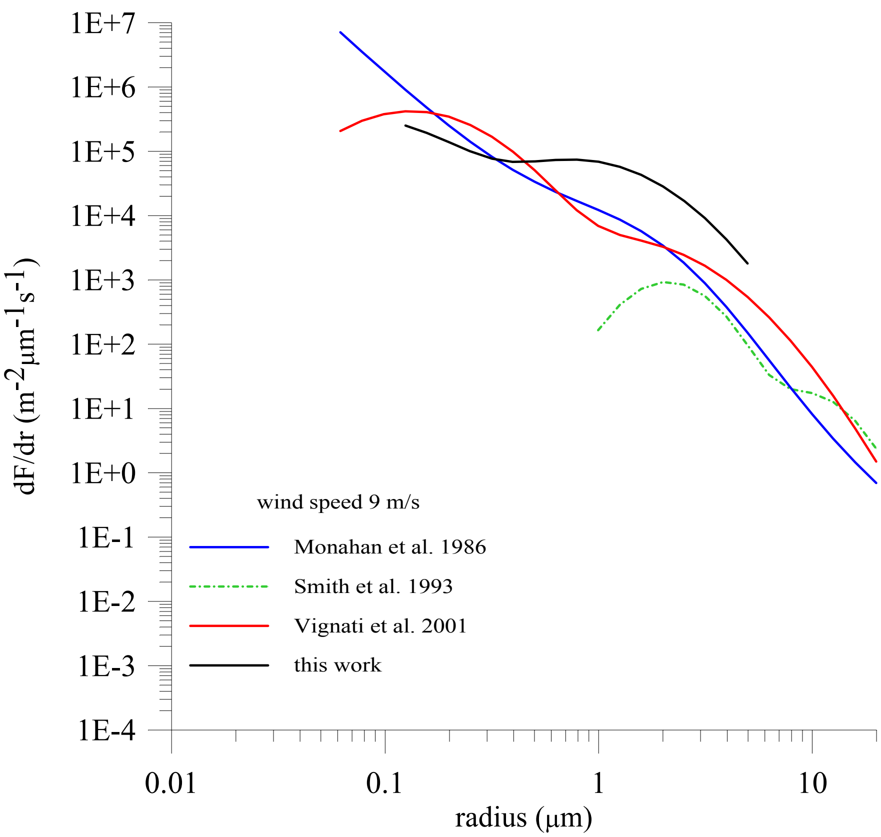


Figure 3. Comparison of source functions derived by Monahan et al. [1986] (blue), Smith et al. [1993] (green), Vignati et al. [2001] (red) and current work (black).

IMPACT/APPLICATIONS

The results can be used to assess the effects of the atmosphere on the performance of thermal imagers over sea, and in particular the performance of LR-IRST systems. Another important application is in the field of numerical weather forecasting because of the influence on the solar irradiation at the Earth surface, as well as the assessment of the impact of aerosols on climate. Sea spray aerosol has been estimated to contribute 44% to the total aerosol optical depth, but with an uncertainty of a factor of three depending on the source function estimate used (IPCC, 2001). The surf-produced aerosol affects atmospheric processes involving sea spray particles, such as heterogeneous reactions, at fetches of at least 10 km in off-shore winds. Reaction between sea spray and HNO_3 has consequences for atmospheric inputs of nitrogen compounds in coastal waters, and thus eutrophication [De Leeuw et al., 2001a;b, 2003a;b]. Over land, sea spray influences fragile coastal eco-systems, and the corrosive properties cause damage to buildings, structures and cultural heritage.

TRANSITIONS

The EOPACE and RED results of TNO-FEL are exchanged with other EOPACE and RED participants, for common analysis combining all required expertise to achieve the EOPACE and RED goals. Common EOPACE publications have been published, others are submitted or in preparation. Accurate sea spray source functions are important in regional and global scale transport models and work is in progress with regional and global scale modelers to promote the use of our results.

RELATED PROJECTS

The efforts described above are in conjunction with other projects addressing electro-optical propagation over sea, in part basic research, in part applied research. They take place in conjunction with studies funded by the Netherlands Ministry of Defense, including work on long-range transmission, IRST and backgrounds. Data from other areas, e.g. the North Sea, the North Atlantic, the Mediterranean and the Baltic, are from other projects supported by the Netherlands Ministry of Defense, the EU or other funding agencies.

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